



# Aerobic Exercise Supplemented with Muscular Endurance Training Improves Onset of Blood Lactate Accumulation

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## Abstract

Muscular endurance training increases muscular endurance; but its ability to improve metabolic and cardio respiratory performance remains unclear. Purpose: The aim of the current Investigation was to evaluate the effect of supplementing an aerobic exercise training program with a muscular endurance training program on various cardio respiratory and metabolic measurements. Methods: Fourteen aerobically active men performed an incremental exercise test to determine the onset of blood lactate accumulation (OBLA), gas exchange threshold (GET), and maximal oxygen uptake ( $VO_2$ max). Maximal strength was measured using 1-repetition max (1-RM) for leg press (LP), leg curl (LC), and leg extension (LE). Eight participants supplemented their aerobic activity (EX group) with 8 weeks of muscular endurance training, while six continued their regular aerobic activity (CON group). Results: No significant group differences were observed for all pre-training variables. Following eight weeks of training no significant differences in body mass, GET, and  $VO_2$ max were observed for either group. However, the EX group showed a significant improvement for  $VO_2$  at OBLA and the percent of  $VO_2$ max at which OBLA occurs. LP, LC, and LE 1-RM assessments for the EX group showed a significant improvement. Conclusion: Muscular endurance training did not improve GET and  $VO_2$ max, but significantly increased  $VO_2$  at OBLA and percent of  $VO_2$ max at which OBLA occurs, which suggests that supplementing aerobic activity with muscular endurance training can improve sub maximal endurance performance via improvements in OBLA.

**Keywords:**  $VO_2$ max; Blood lactate concentration; Aerobic performance;  $VO_2$

## Introduction

It has been well established that indices of blood lactate concentration specifically onset of blood lactate accumulation (OBLA) provide a valid measurement of sub-maximal exercise capacity and has a stronger correlation with endurance performance than maximal oxygen uptake ( $VO_2$ max) [1-4]. OBLA is the metabolic rate or workload at which blood lactate concentration begins to increase exponentially and has been shown corresponded to a fixed blood lactate of 4 mmol/L in already aerobically trained individuals [4]. Figueira et al. [5], demonstrated an OBLA corresponding to 4 mmol/L of lactate concentration represented the maximal workload of steady state lactate concentration and corresponded to the point at which exercise intensity transitions from tolerable (ability to clear lactate) to severe (accumulation of lactate resulting in fatigue) in active individuals [5]. Since OBLA is a significant determinant of endurance performance [6], a number of investigations have focused on identifying targeted training strategies aimed at increasing OBLA. The conclusions from several of these studies suggest that the primary stimulus for significant post-training increases in OBLA is a consistent training session induced accumulation of blood lactate [7,8]. To date, a majority of the protocols developed have utilized aerobic exercise training to induce blood lactate accumulation with the overall goal of improving OBLA. However, muscular endurance training (high volume resistance training utilizing a low external resistance) [9], consists of individual exercise session that have been shown to induce a large drop in blood pH and a subsequent increase in blood lactate concentration [10,11] similar to that reported during an aerobic interval training session [10,12,13] and greater than that of a traditional strength training session [14,15]. Therefore it seems feasible that a high volume resistance training program could elicit similar or greater physiological responses within a given training session compared to that of aerobic interval training session, thus providing a greater stimulus for improvements in indices of aerobic performance markers such as OBLA. Since, many individuals perform comprehensive training regimens consisting of both aerobic and resistance training components (e.g., concurrent training), it is therefore important to improve our understanding as to how modifications made to a concurrent training program, particularly, with resistance training, influence aerobic exercise

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capacity and performance. Therefore, the purpose of the study was to examine the adaptations induced by supplementing an aerobic training program with a high volume muscular endurance training program. It was hypothesized that supplementing an aerobic training program with a muscular endurance training program would result in an improved OBLA (i.e., 4 mmol/L would occur at a higher exercise intensity), an improved gas exchange threshold (GET), an index of the lactate threshold [16], and  $\text{VO}_2\text{max}$  when compared to aerobic training alone.

## Materials and Methods

### Participants

14 men were recruited for the current study (18-40 years old). Participants were randomly divided into an experimental (EX) group, whose regular aerobic training was supplemented with a high volume muscular endurance training program, or a control (CON) group who continued their regular aerobic exercise training without the addition of muscular endurance training. All participants were considered to be aerobically active and had not participated in resistance training on more than one day per week for four months prior to start of the study; determined with a self-reported physical activity questionnaire. Aerobically active was defined as having participated in aerobic exercise at least one hour per day for 3 days per week for the past 6 months. Participants were from a diverse background of aerobic activities. The experimental group consisted of: 2 runners, 4 cyclist, and 2 triathletes while the control group consisted of: 2 runners and 4 cyclists. Participants' baseline  $\text{VO}_2$  ranged from 43.5 to 61.5 ml/kg/min and therefore were all classified as aerobically active. All participants were free from cardiovascular, pulmonary, or metabolic disease and were non-smokers determined from a medical history questionnaire. This study was approved by the Institutional Review Board, and each participant gave a verbal and written informed consent before participation. All testing and training was completed in an air-conditioned laboratory at a temperature 20-25°C.

### Experimental protocol

Prior to the training period both groups were required to perform a staged graded exercise test to determine OBLA of 4mmol/L, GET and,  $\text{VO}_2\text{max}$ . Both groups were also required to perform 1-repetition maximum (1-RM) strength testing for leg press (LP), leg curl (LC), and leg extension (LE). Both groups were instructed to continue their current level of aerobic activity, which in all participants consisted of long slow steady-state exercise bouts. In addition to their current aerobic training the EX group returned to the laboratory two times per week for eight weeks to perform muscular endurance training sessions under the supervision of the researchers. Following the experimental period, the participants returned to the laboratory for post-testing. Incremental Exercise Test. A magnetically braked cycle ergo meter (Sport Excalibur, Lode; B.V. Medical Technology, Groningen, The Netherlands) along with a metabolic cart (True One 2400, Parvo Medics, Sandy, UT) was utilized to perform an incremental exercise test to determine  $\text{VO}_2\text{max}$  and GET. A cycle ergo meter test was chosen to allow for easy attainment of plasma lactate measurements. Participants were instructed to abstain from exercise and caffeine twelve

hr prior to testing and to fast three to four h prior to testing. A urine sample was obtained to determine urine specific gravity using a refractometer (model CLX-1, VEE GEE Scientific Inc., Kirkland, WA). Participants had to have a urine specific gravity between

1.004 and 1.026 to be considered adequately hydrated to perform the incremental exercise test. In the instance a participant was not adequately hydrated they were instructed to consume a glass of water and rest for 30 minutes before collecting a second sample. If at that time they were still under hydrated they were rescheduled for a subsequent day. A resting fingertip capillary blood sample was collected to determine whole blood lactate concentration prior to testing using a commercial lactate meter (Lactate Plus, Nova Biomedical, Waltham, MA) that was calibrated with known lactate standards (Lactate Plus, Lac Control Level 1, 1.0-1.6 mM) (Lactate Plus, Lac Control Level 2, 4.0-5.4 mM) before each use. Following a one minute rest period and a five minute warm up at 50 watts (W), the staged exercise test was initiated at a work rate of 125 W and increased by 25 W every three minutes until the participant reached their limit of exercise tolerance indicated by a pedal rate dropping below 50 revolutions per minute. At the end of each of the three-minute stage we measured blood lactate and rating of perceived exertion (RPE) based on the Borg Scale (Borg, 1970). The  $\text{VO}_2$  corresponding to 4.0 mmol/L (OBLA) was calculated by plotting  $\text{VO}_2$  against blood lactate concentration and using linear interpolation.

Metabolic and ventilatory data were continuously measured and averaged over 30 second intervals. The work rate corresponding to the GET was determined as the point in which  $\text{VCO}_2$  increased out of proportion to  $\text{VO}_2$  and with an increase in  $\text{VE}/\text{VO}_2$  and no increase in  $\text{VE}/\text{VCO}_2$  [16]. Heart rate (HR) was measured via a telemetric heart rate monitor (Polar T31, Polar Electro Inc., NY, USA). 1- Repetition Maximum (1-RM) Testing. 1-RM testing was performed to assess maximum strength for leg press (LP), leg curl (LC) and leg extension (LE) based on recommendations from the National Strength and Conditioning Association (NSCA) [9]. In brief, several sub-maximal repetitions were performed to serve as a warm-up. An initial weight was selected to be within 50 to 70 percent of the participant's perceived capacity. The weight was increased incrementally until a weight that could be lifted once but not twice was achieved. Three minutes of rest was given between each attempt. If a participant was able to lift the entire weight stack they were required to complete a full range of motion and immediately attempt additional repetitions through a full range of motion until failure. The number of additional repetitions was then used to calculate their 1-RM [9]. Aerobic Exercise. Participants were instructed to maintain their current aerobic activity, which consisted of long slow duration training, and not increase either their training distance or intensity during the experimental period. In order to best control for outside activity participants were instructed to maintain a journal of their aerobic training. Upon each visit to the laboratory the participants' journals were inspected by the researchers to insure that aerobic training duration of the participants did not decrease by no more than 1/3 to prevent reductions in aerobic performance (detraining) [17], and did not increase by more than 5 percent overall to prevent any improvements in aerobic performance from the aerobic training [9,18]. If it was found that the participants had not followed these guidelines they were removed from the study. Muscular endurance training. Currently, NSCA recommends lighter loads (i.e.,  $\leq 67\%$  of 1RM) with higher number of repetitions ( $\geq 12$ ) for muscular endurance training [9]. The muscular endurance training program utilized in the current study consisted of supervised sessions on 2 days $\cdot\text{wk}^{-1}$  over an eight week period (16 sessions) to supplement each participants off-season aerobic training program. Participants were instructed to not perform any resistance training outside of the study. If it was learned

**Table 1:** Subject Characteristics (Mean ± SD).

Variables	Groups			
	Experimental (n = 8)		Control (n = 6)	
	Pre	Post	Pre	Post
Age (years)	23.5 ± 2.1	23.7 ± 2.1	20.5 ± 0.8	20.7 ± 1.0
Height (cm)	181.1 ± 4.3	181.1 ± 4.3	179.5 ± 5.0	179.5 ± 5.0
Body Mass (kg)	74.7 ± 3.7	75.1 ± 4.3	75.0 ± 7.4	74.6 ± 8.4

Differences if present were denoted using \* (p<.05). Standard deviations represent variability.

**Table 2:** Delta Scores (Post- Pre) in Physiological Data during Incremental Exercise Test (Mean ± SD).

Variable	Groups		
	Experimental (n = 8) Control (n = 6)		Effect Size
	Δ	Δ	
VO <sub>2</sub> max Abs (l/min)	-0.039 ± 1.64	-0.230 ± 0.303	.08
VO <sub>2</sub> max Rel (ml/kg/min)	-0.725 ± 2.23	-2.68 ± 3.30	.77
GET (l/min)	0.036 ± 0.288	-0.050 ± 0.288	.32
Watts @ GET	6.00 ± 24.7	-3.17 ± 18.06	.45
VO <sub>2</sub> (L/min) @ OBLA	0.253 ± 0.245 <sup>†</sup>	-0.122 ± 0.324	1.44
VO <sub>2</sub> (ml/kg/min) @ OBLA	3.15 ± 3.06 <sup>†</sup>	-1.42 ± 3.91	1.44
% of VO <sub>2</sub> max OBLA achieved	7.15 ± 6.54 <sup>*</sup>	0.557 ± 7.93	1.00

Δ denotes delta scores (post – pre). Differences within groups from pre to post were denoted using

\* (p<.05) and differences between groups were denoted using † (p<.05). Standard deviations represent variability. VO<sub>2</sub> Abs: Absolute VO<sub>2</sub>; VO<sub>2</sub> Rel: Relative VO<sub>2</sub>; GET: Gas Exchange Threshold;

OBLA: Onset of Blood Lactate Accumulation at 4mmol/L of lactate.

that an individual was not properly following study guidelines they were removed from the study. Each session began with a warm up session consisting of several repetitions at 30 to 40 percent of their 1-RM. The muscular endurance program included four sets of 12 to 15 repetitions at 50 percent of their established 1-RM for three lower body exercises (LP, LC, and LE; Cybex Strength Systems) in that fixed order. One minute of rest was provided between sets and three minutes between exercises. If during the training session a participant was unable to complete the prescribed 12 to 15 repetitions, they were instructed to perform as many repetitions as possible until failure (i.e., a full range of motion could not be successfully completed). After 4 weeks (8 training sessions) the training weight was increased by 4.54 kilograms (a 2 to 4 percent increase) if an individual was able to complete four sets of 15 repetitions to compensate for any strength gains [9]. If participants were unable to complete four sets of 15 repetitions the training weight was kept the same.

**Statistical analysis**

Data is presented as mean ± SD. Delta scores (post-pre) are indicated by Δ. Delta scores were used for data analysis to negate any differences noted in pre measurements due to both groups consisting of individuals that participated in several different aerobic activities (swimmers, cyclists, runners and triathletes). In addition the incremental exercise test was not sport specific for all participants. Paired t-test were used to test for significant differences between pre- and post-intervention. T-tests were utilized to determine if significant between group differences existed between the EX and CON groups. All statistical analyses was performed using Sigma Plot (Version 12.5, Systat Software Inc., San Jose, CA). Cohen’s d effect sizes (ES) were reported for all significant measures. A value of ≤ 0.20 was considered

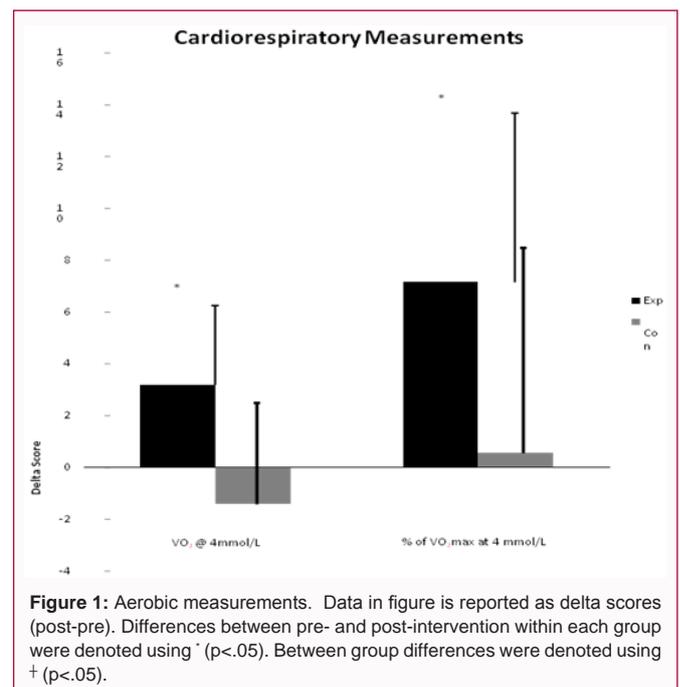
a weak effect, a value of ≤ 0.50 was considered a moderate effect, and a value of ≥ 0.80 was considered a strong effect [19]. An alpha level of p ≤ 0.05 was set for the level of significance.

**Results**

Descriptive characteristics are summarized in (Table 1). No significant differences existed between groups for age, height, and body mass as well as within each group following 8 weeks. Of the 8 participants included in the EX group only 1 participant failed to obtain at least 12 repetitions per set on six sets. Out of the possible 192 sets of resistance training this participant was able to complete the prescribed repetition scheme for 186 sets (96.8%).

The delta scores for key physiological measurements obtained from the incremental exercise test are summarized in (Table 2) for each group. In the EX group, no significant differences were observed following the training program for: absolute VO<sub>2</sub>max (VO<sub>2</sub>max Abs, L/min), relative VO<sub>2</sub>max (ml/kg/min), GET (L/min), watts (W) at GET, and Max W. However, following training the EX group showed significant improvement in both absolute and relative VO<sub>2</sub> at the OBLA set to 4 mmol/L (p = 0.022; ES = 1.56 and p = 0.023; ES = 1.56, respectively). Similarly, the %VO<sub>2</sub>max at which OBLA occurred was significantly higher following training in the EX group (p=0.017; ES=1.65). No significant improvements were observed for any of the tested variables from the incremental exercise test in the CON group following training. Pre-training no significant differences were observed between EX and CON for: absolute and relative VO<sub>2</sub>max, GET, W at GET, and Max W. However, following training the EX group showed significant improvements compared to the CON group for the absolute (p = 0.015; ES=1.31) and relative (p = 0.014; ES=1.30) VO<sub>2</sub> at an OBLA of 4mmol/L (Figure 1).

Maximal strength values are summarized in (Table 3) and illustrated in (Figure 2). No significant differences were observed in the CON group for LP, LC, and LE. However, following training the EX group showed significant improvements in LP (p = 0.009; ES=1.90), L (p = <0.001; ES=4.80), and LE (p = <0.001; ES=5.23). Comparing the groups following training the EX group showed

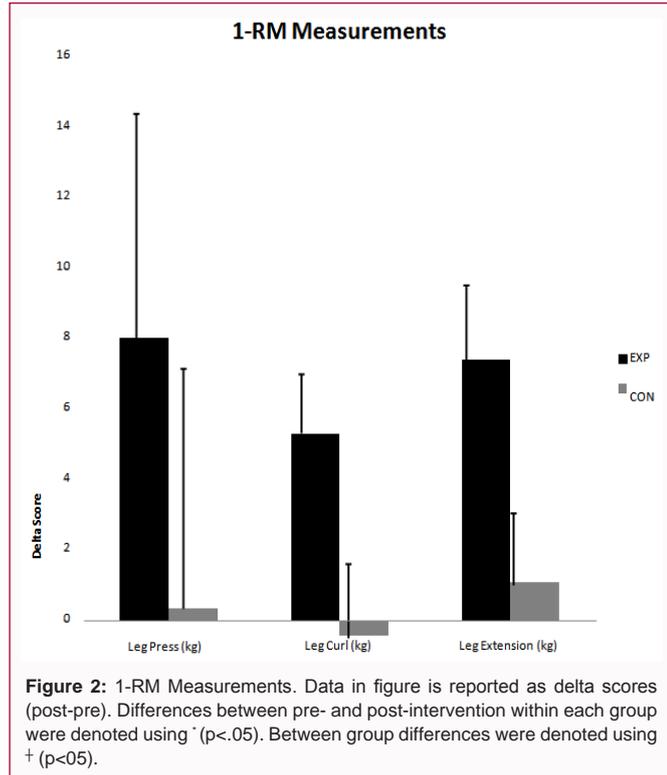


**Figure 1:** Aerobic measurements. Data in figure is reported as delta scores (post-pre). Differences between pre- and post-intervention within each group were denoted using \* (p<.05). Between group differences were denoted using † (p<.05).

**Table 3:** Delta Scores (Post- Pre) in 1-RM Measurements (Mean ± SD).

Groups			
Experimental (n = 8) Control (n = 6)			
Variable	Δ	Δ	Effect Size
Leg Press (kg)	8.02 ± 6.39 <sup>*</sup>	0.343 ± 6.83	1.31
Leg Curl (kg)	5.30 ± 1.67 <sup>+</sup>	-0.453 ± 2.17	3.28
Leg Extension (kg)	7.40 ± 2.14 <sup>+</sup>	1.07 ± 2.06	3.24

Δ denotes delta scores (post – pre). Differences within groups from pre to post were denoted using \* (p<.05) and differences between groups were denoted using † (p<.05). Standard deviations represent variability.



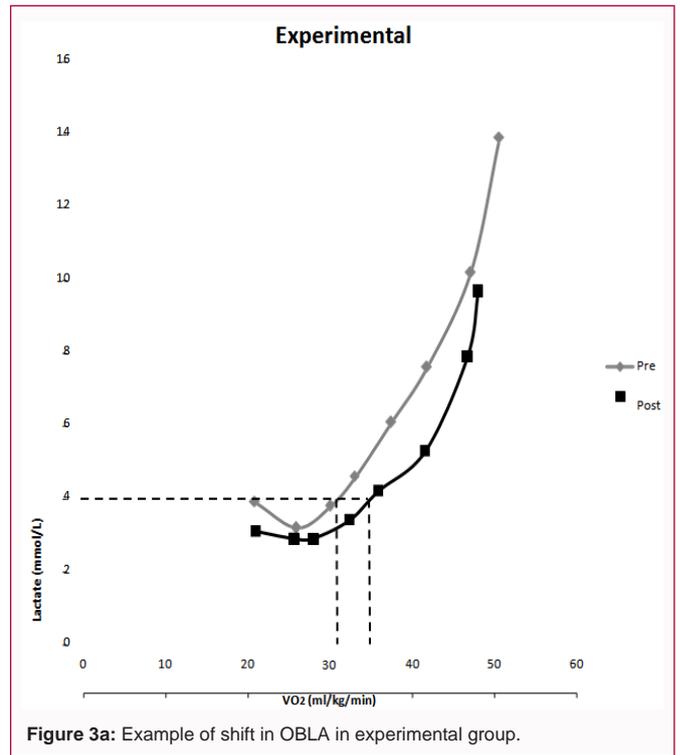
**Figure 2:** 1-RM Measurements. Data in figure is reported as delta scores (post-pre). Differences between pre- and post-intervention within each group were denoted using \* (p<.05). Between group differences were denoted using † (p<.05).

significant improvements in LC ( $p = <0.001$ ; ES=2.97) and LE ( $p = <0.001$ ; ES=3.01) compared to the CON group.

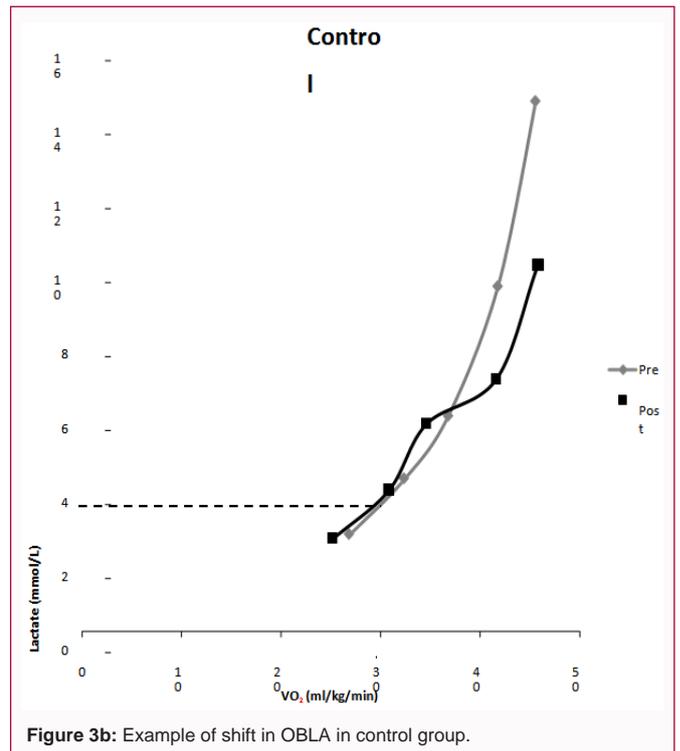
Delta Scores (Post- Pre) in 1-RM Measurements (Mean ± SD).

### Discussion

The main purpose of the study was to examine the cardio respiratory and metabolic adaptations obtained by supplementing an endurance training program with a muscular endurance training program. In support of our first hypothesis supplementing an aerobic training program with a muscular endurance training program significantly increased OBLA to a greater extent than aerobic training alone. However, in contrast to our second hypothesis, the addition of muscular endurance training program did not improve  $VO_{2max}$  or GET. The current training protocol was designed in an attempt to elicit similar cardio respiratory and local muscular response to that commonly observed with circuit weight training and aerobic interval training. It was speculated that the high volume would induce an accumulation of lactate and hydrogen ions, and short rest periods (1 min) would not allow for the lactate to be completely shuttled from active musculature. Previous investigations that have examined the effects of circuit weight training in untrained adults



**Figure 3a:** Example of shift in OBLA in experimental group.



**Figure 3b:** Example of shift in OBLA in control group.

suggest that it can be used to improve  $VO_{2max}$  [20,21], which lead to the speculation that this muscular endurance training program may elicit similar improvements in  $VO_{2max}$ . However, the current study saw no significant improvements in  $VO_{2max}$  following training but could be explained in part that the participants in the current study were aerobically active while previous studies consisted of sedentary participants [20,21]. The findings of the current study agree with previous concurrent training studies that observed improvements in indices of endurance performance but not  $VO_{2max}$  [22-24].

For instance, Hoff et al. [23], demonstrated an increased time to exhaustion, but no improvement in  $\text{VO}_2\text{max}$ , in cross country skiers whose current endurance training was supplemented with 8 weeks of strength training. Similarly, Johnston et al. [24], observed an increase in running economy following 10 weeks of concurrent strength and endurance training without improvements in  $\text{VO}_2\text{max}$ . Although different resistance training protocols were used in the previously mentioned studies from the current study, all showed a non-significant improvement in  $\text{VO}_2\text{max}$ , but significant improvements in factors associated with increased endurance performance. Unlike the GET and  $\text{VO}_2\text{max}$ , the  $\text{VO}_2$  at 4mmol/L of blood lactate increased in the EX group following training. (Figure 3a). Illustrates the shift of the OBLA in the EX group resulting in the OBLA occurring at a higher percentage of the  $\text{VO}_2\text{max}$  while (Figure 3b). Illustrates no shift in the OBLA for the CON group (Figure 3a and b). are individual data that most closely represent the group averages). The percent of  $\text{VO}_2\text{max}$  at which OBLA occurred improved significantly following training in the EX group. This improvement translated into OBLA occurring 7.2% closer to the participants'  $\text{VO}_2\text{max}$  (pre-training 65.3% vs. post-training 72.5%). A reduced lactate production, improved clearance, or a combination of both could explain the higher  $\text{VO}_2$  at a lactate of 4 mmol/L seen in the present study following muscular endurance training. An improvement in the utilization of lipids at higher work rates would result in the delay in the accumulation of lactate [25]. Likewise, an improved blood lactate clearance could be possible with no changes in the rate of lactate production [26]. Despite the underlying mechanism, the higher  $\text{VO}_2$  at 4 mmol/L of blood lactate would likely translate into better endurance performance as it allows individuals to maintain a higher relative (%  $\text{VO}_2\text{max}$ ) exercise intensity [5,6]. For instance, Fay et al. [6], demonstrated that the  $\text{VO}_2$  corresponding to an OBLA at 4mmol/L explained greater than 80% of the variance in race pace in elite women runners at 5, 10, and 16.09 kilometer distances. These findings suggest that any increase in the  $\text{VO}_2$  achieved at 4 mmol/L resulted in the ability to maintain a faster race pace. Although a delay in the accumulation of blood lactate to 4 mmol/L was observed, there were no significant improvements in GET. It has been suggested that the improvements in GET are related to improvements in oxidative muscle capacity and not solely based on the rate of production and removal of lactate [27]. The dissociation between the significant improvement in OBLA and lack of significant increase in GET suggests that the training adaptations of the two parameters are partially controlled by different mechanisms. This is an important finding showing that muscular endurance training can be used to augment aerobic endurance performance in aerobically active individuals, despite no improvements in GET or  $\text{VO}_2\text{max}$ .

Participants in the EX group showed increased 1-RM strength for leg press, leg curl, and leg extension. Campos et al. [28], also demonstrated that a volume resistance training program could improve 1RM strength. This is an interesting finding because the current training protocol was designed to induce an accumulation of lactate and hydrogen ions and to improve muscular endurance, but not necessarily to improve muscular strength. Traditionally to improve muscular strength 75-95% of 1RM is used with sets of 4-10 repetitions [9], while the current study used 50% of 1RM and sets of 12 to 15 repetitions. It can be speculated that the strength gains shown in the current study are related to improved neural recruitment associated with beginning resistance training since participants had not participated in consistent resistance training for more than one day per week for at least 4 months prior to the start of the study.

Although significant differences were observed following training within the EX group for both the percent of  $\text{VO}_2\text{max}$  at which OBLA occurred and leg press, no significant differences between the two groups were observed for these measurements. The lack of significant group differences can possibly be explained by a lack of statistical power (0.487 and 0.652 respectively) for these two measurements. It can be speculated that if more participants participated in the study group differences for these two variables could be seen. Although the aerobic training of participants was not directly monitored by the researchers, as it was performed outside the laboratory setting; the researchers do not believe that this aspect of the study negates any of the findings of the current study and provides for a real world application. Additionally, all participants' training journals were inspected by the researchers to insure that aerobic training duration of the participants did not decrease by no more than 1/3 to prevent reductions in aerobic performance (detraining), and did not increase by more than 5 percent overall. A similar experimental design was utilized by Hickson et al. [29], and recently by Karsten et al. [30], where all strength training was performed under the supervision of the researchers while all aerobic training was performed independently outside the lab when evaluating the potential for simultaneous strength and endurance training to improve endurance performance.

## Conclusion

In conclusion, supplementing a steady-state aerobic training program with an 8 week high volume resistance training protocol did not show a significant improvement in  $\text{VO}_2\text{max}$  or GET. However, significant improvements in absolute, relative, and %  $\text{VO}_2$  at 4 mmol/L of blood lactate and 1-RM for leg press, leg curl, and leg extension were observed. These findings indicate individuals are capable of exercising at a higher percentage of their  $\text{VO}_2\text{max}$  before reaching their OBLA (4 mmol/L used herein). However, more research is needed to determine how to appropriately implement this type of training into an effective training protocol and if real-world endurance performance is increased. With several different modalities of endurance exercises represented in the participant pool the current study demonstrates the current training protocol can be applied to several different endurance modalities and improve blood lactate accumulation. This style of resistance training could potentially provide the same benefits of traditional strength training (improved 1- RM and running economy) with the added benefits of improved OBLA. Further research is needed to determine all potential benefits from muscular endurance training for aerobic training as well as further understanding of how to program and implement this training modality into the training programs of aerobic athletes.

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